

# Use of Chemical Sanitizers To Reduce Microbial Populations and Maintain Quality of Whole and Fresh-Cut Cantaloupe<sup>†</sup>

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## ABSTRACT

Whole cantaloupes either not inoculated or inoculated with *Salmonella* Poona were submerged in water, 180 ppm of chlorine, acidified calcium sulfate (ACS: 1.2% Safe<sub>2</sub>O-ACS50), 1,000 ppm of acidified sodium chlorite (ASC), 80 ppm of peroxyacetic acid (PAA), and a combination of ACS and PAA for 10 min. Although only ASC and the combination of ACS and PAA significantly reduced the aerobic plate count of samples taken from the surface of whole cantaloupe (compared with samples taken from cantaloupe submerged in water only), all treatments reduced yeast and mold counts on the whole cantaloupe. However, none of the treatments of whole cantaloupes consistently reduced yeast and mold counts for the samples of fresh-cut cantaloupes. The aerobic plate counts for fresh-cut cantaloupe were reduced by 1 to 2 log CFU/g by sanitization of whole fruit with ASC, ACS, and the combination of ACS and PAA. The low bacterial population on the fresh-cut fruit was maintained during 14 days of storage at 4°C. All treatments had a limited effect on the population of *Salmonella*, achieving no more than a 1.5-log reduction of the pathogen inoculated on the surface of the whole cantaloupes. *Salmonella* was nondetectable via direct plating (with a detection limit of 0.4 log CFU/g) in fresh-cut cantaloupes prepared from whole cantaloupes treated with any of the sanitizers. However, after enrichment, *Salmonella* often was detectable. Color, texture, soluble solids, pH, ascorbic acid, and drip loss of cut cantaloupes were not consistently affected by any of the whole-fruit treatments. Overall, treatments of whole cantaloupe with ASC, ACS, and the combination of ACS and PAA at the concentrations tested permitted a significant reduction in *Salmonella* and native microflora of whole and cut fruit; however, *Salmonella* still could be found in cut cantaloupes from all treatments.

In recent years, the number of outbreaks of foodborne illness associated with fresh fruits and vegetables has been increasing in the United States. Of these produce-related outbreaks, 25% were associated with fresh-cut produce (25). An increase in global trade, a longer food chain, an increase in consumption of raw produce, and an aging population that is susceptible to foodborne illnesses may play a role in the increased number of foodborne illnesses associated with fresh produce (25). Cantaloupes and other melons are commonly associated with outbreaks. The U.S. Food and Drug Administration (FDA) surveys revealed a higher incidence of *Salmonella* contamination on whole cantaloupe melons of both imported and domestic origin than on many other fruits and vegetables (23, 24). Fresh-cut cantaloupe, either as a single-component product or as part of multicomponent fruit salads, is available all year in the United States. Fresh and fresh-cut cantaloupes have been associated with a number of recent salmonellosis outbreaks (7–9). Decontamination of whole cantaloupes by using sanitizers may be an option to improve the safety of whole and cut fruit.

Chlorine is routinely used as a sanitizer by produce processors, but its effectiveness for reducing foodborne human pathogens and native microflora is limited (15, 22). The use of chlorine also is a concern because of the potential formation of carcinogenic organochlorine compounds (20). Chlorine can rapidly react with organic materials that are released from raw produce into solution and with organic matter on the surface of fresh or fresh-cut produce, which results in a rapid decline in the chlorine concentration. Several antimicrobials have been investigated for reducing the microbiological population on the surface of fresh and fresh-cut produce.

Recently, a sanitizer based on acidified calcium sulfate (ACS) has been developed to reduce the total number of aerobic bacteria and pathogens in meat products (27). ACS has been approved for use on meat by the U.S. Department of Agriculture (USDA) Food Safety and Inspection Service. ACS in combination with organic acids increased the thermal sensitivity of *Escherichia coli* O157:H7 in ground beef. Nunez de Gonzalez et al. (19) found minimal changes in the sensory properties of frankfurters rinsed with ACS and propionic acid. Mehryar et al. (17) found that treatment with acidified sodium chlorite (ASC) and ACS generally resulted in a greater reduction of *Salmonella* on chicken drumettes than did treatment with cetylpyridinium chloride and peroxyacetic acid (PAA). Luchansky et al. (16) found that application of ACS appreciably reduced levels of

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*Listeria monocytogenes* on the surface of hams within 24 h at 4°C and that ACS had potential for controlling outgrowth of the pathogens during 60 days of storage.

Various acidified compounds have been used as sanitizers, although their mode of action may not be solely due to low pH. ASC (Sanova, Ecolab, Inc., St. Paul, MN) is produced by adding a weak organic acid such as citric acid to a solution of sodium chlorite ( $\text{NaClO}_2$ ). PAA ( $\text{CH}_3\text{CO}_3\text{H}$ ) is another sanitizer commonly used in many segments of the food industry. Commercial PAA sold as a sanitizer often is a mixture of PAA and hydrogen peroxide (e.g., Tsunami 100, Ecolab). Unlike chlorine, the three acidified sanitizers (ACS, ASC, and PAA) are claimed to be effective in the presence of organic matter. According to the manufacturers, no posttreatment rinse is required after use of these materials when produce is further processed.

Although the efficacy of ASC and PAA as antimicrobials has been studied on various types of produce (4, 6, 12), limited studies have been conducted on the use of these compounds on cantaloupes, and there is no report on the use of ACS on fresh produce. The objective of this study was to investigate the sanitizing effect of ACS in comparison with ASC, PAA, and chlorine on indigenous microbial populations on whole cantaloupe and the effects of these compounds on the quality of fresh-cut melon during storage at 4°C.

## MATERIALS AND METHODS

**Cantaloupes and sanitizers.** Size 12 California cantaloupes (*Cucumis melo* L. var. *cantalupensis* Naud, cv. Ore Rico) were provided by Del Monte Fresh Produce Company through its Philadelphia distribution center. The fruits were stored at 4°C overnight before being used. The average weight of each fruit was  $1,369 \pm 136$  g. Sanova and Tsunami 100 were provided by Ecolab, and ACS (Safe<sub>2</sub>O-ACS50) was from Mionix, Inc. (Rocklin, CA).

**Preparation of sanitizers.** Chlorine was prepared from 6% sodium hypochlorite ( $\text{NaOCl}$ ) in 0.02 M phosphate buffer (pH 6.5). After proper dilution with distilled water, concentrations of free chlorine in the solution were measured with Refectoquant strips and the Merck RQflex plus system (LRE Relais und Elektronik GmbH, Munich, Germany) during treatment. The free chlorine concentrations were 180, 169, and 159 ppm at 0, 5, and 10 min of treatment, respectively. Generally recommended free chlorine concentrations and pH in produce packing lines are 100 to 200 ppm and 6.5 to 7.5, respectively. The 80 ppm of PAA (Tsunami 100) and 1,200 ppm of ASC (Sanova) were prepared following the manufacturer's instructions. ASC was prepared by slowly adding citric acid solution to the base sodium chlorite solution until the pH reached 2.5. The ASC solution was used within 20 min of preparation. As suggested by the manufacturer, the Safe<sub>2</sub>O-ACS50 was diluted with water to reach pH 1.5 resulting in a Safe<sub>2</sub>O-ACS50 concentration of about 1.2%. For the combination treatment, 1.2% Safe<sub>2</sub>O-ACS50 was prepared first and then PAA was added to a final concentration of 80 ppm.

**Treatment of whole fruit.** Randomized cantaloupes (three per treatment) were submerged in 10 liters of water or sanitizer solution with either 180 ppm of free chlorine (pH 6.5), 80 ppm of PAA, 1,200 ppm of ASC, ACS (1.2% Safe<sub>2</sub>O-ACS50), or the

combination of PAA and ACS in 40-liter plastic buckets. The temperature of the solutions was 7°C, and treatment time was 10 min. Solutions were agitated during treatments using a shaker (model M49125, Barnstead International, Dubuque, IA) at 50 rpm. Samples were not rinsed in water after the sanitization treatment. Each treatment was repeated four times using a different set of cantaloupes and freshly prepared solutions. The whole experiment was then repeated once using fruits obtained on a different date.

**Preparation of fresh-cut cantaloupe.** Fresh-cut cantaloupes were prepared the day after the treatment of whole cantaloupes. During overnight storage (7°C), the three whole cantaloupes were covered by plastic bags. All preparations were conducted in a food processing cold room (7°C) under strict sanitary conditions. All utensils and equipment used for preparing fresh-cut pieces were sanitized by immersion in 300 ppm of chlorinated water for 5 min. After treatments, the fruits were uniformly peeled using a mechanical fruit peeler as previously described (1). The rinds were weighed and saved for microbial analysis. The peeled melons were sliced once longitudinally, seeds were removed, and the seed cavity was cleaned manually. Halves were cut into approximately 2- to 3-cm slices, and cubes were prepared from the slices. The average weight of a cube was  $20 \pm 5$  g. For replicates of each experiment, cubes from three fruits were randomized, and  $409 \pm 24$  g of cubes was placed into 16-oz (480-ml) polystyrene clamshell containers (Dart Container Corp., Mason, MI). All fresh-cut cantaloupe samples were then stored for up to 14 days at 4°C. After 0, 1, 7, 11, and 14 days of storage, samples were analyzed for firmness, color, soluble solids content, pH, titratable acidity, drip loss, ascorbic acid, and sensory quality characteristics. Cantaloupe rinds from melons and fresh-cut cube samples were analyzed for total aerobic bacterial plate count (APC) and yeasts and molds. Analyses of the quality characteristics and aerobic bacteria have been reported previously (11). Brief descriptions of the procedures are given below.

**Sampling protocols for determination of aerobic microorganisms.** Whole rinds from each cantaloupe were combined with three times (wt/vol) the amount of 0.52% neutralizing buffer (BBL, Becton Dickinson, Sparks, MD) and blended at medium speed for 1 min with a commercial blender (model 51BL31, Waring Products, Torrington, CT). Cubes (100 g) were blended with a 1:1 dilution of 0.1% peptone water (PW; BBL, Becton Dickinson) for 1 min. The resulting homogenate was placed in a filter bag (Spiral Biotech, Bethesda, MD), and duplicate 10-ml filtrate samples were transferred to sterile tubes. Filtrates were then serially diluted in PW as needed and surface plated on tryptic soy agar (TSA; BBL, Becton Dickinson) for APCs and on yeast and mold Petrifilm (3M, St Paul, MN) for yeast and mold counts. The TSA plates were incubated for 24 h at 35°C, and the Petrifilms were incubated at room temperature ( $19 \pm 1^\circ\text{C}$ ) for 5 days. Colonies were counted manually. Populations of microorganisms were expressed as log CFU per square centimeter of rind and per gram of fresh-cut cubes.

**Inoculation of whole cantaloupe with *Salmonella* Poona.** *Salmonella* Poona RM-2350, a clinical isolate associated with a cantaloupe outbreak (ERRC culture collection, Wyndmoor, PA), was used in the inoculation study. The maintenance and growth conditions of the *Salmonella* have been reported previously (1). A loopful of culture from a *Salmonella* stock that had been maintained on TSA slants was transferred into 10 ml of tryptic soy broth (TSB; BBL, Becton Dickinson) and allowed to grow for 8 h at 35°C. This culture was then transferred to 2 liters of TSB

and allowed to grow overnight. The bacterial cells were then spun down at  $6,740 \times g$  for 20 min and washed twice with 400 ml of sterile distilled water. Pellets were suspended in 3.6 liters of sterile distilled water to make up the inoculum. The population in the inoculum was about  $9 \log$  CFU/ml. Cantaloupes were inoculated by submerging in the inoculum for 5 min. Inoculated cantaloupes were then drained, allowed to air dry in a biosafety cabinet for 2 h, and stored in plastic tubs at  $4^\circ\text{C}$  overnight.

**Treatment of inoculated cantaloupes.** The inoculated fruits used for sanitizer treatments were handled exactly as were the noninoculated fruit. After the sanitizer treatments, the inoculated cantaloupes were stored at  $4^\circ\text{C}$  overnight. Then the cantaloupe rind was peeled with a semiautomatic all-fruit peeler, which was sanitized with 70% ethanol between samples (1). *Salmonella* populations on the rind were determined on the same day of peeling. The peeled cantaloupes were cut into cubes as described above. All fresh-cut cantaloupe samples were then stored for up to 14 days at  $4^\circ\text{C}$ . *Salmonella* populations were determined after 0, 1, 7, 11, and 14 days storage.

**Enumeration and enrichment of *Salmonella*.** Rind and fresh-cut cantaloupe samples (100 g each) were mixed with lactose broth 1:3 (wt/vol) and 1:1 (wt/vol), respectively, for primary enrichment and blended in a Waring blender for 1 min. To assess uninjured *Salmonella* cells, the blended samples were plated on the selective agar xylose lysine tergitol 4 (XLT-4, BBL, Becton Dickinson) and incubated for 24 h at  $35^\circ\text{C}$ , and resultant colonies were counted manually. To assess the number of injured cells, the blended samples were plated on TSA plates, incubated at  $35^\circ\text{C}$  for 2 h to allow recovery of injured cells, and then overlaid with XLT-4. The overlaid plates were incubated for 24 h at  $35^\circ\text{C}$  and then colonies were counted.

Because of the low number of *Salmonella* cells recovered from fresh-cut cantaloupe samples, a selective enrichment was conducted on samples that were negative by direct plating. For the primary enrichment, all blended fresh-cut samples were incubated for 24 h at  $35^\circ\text{C}$  without shaking. For the selective enrichment, 9 ml of selenite cystine broth (BBL, Becton Dickinson) was mixed with 1 ml of the primary enriched cantaloupe homogenate and incubated at  $35^\circ\text{C}$  for 24 h with shaking. The enriched sample was then streaked on XLT-4, incubated at  $35^\circ\text{C}$  for 24 h, and then examined to determine whether the sample was positive for *Salmonella* Poona.

**Texture measurement.** On each sampling day, four fresh-cut cubes from each replicate (package) were selected. Penetration tests were conducted on the cubes using a TA-XT2i texture analyzer (Texture Technologies Corp., Scarsdale, NY). Cubes were cut to achieve a level surface for texture analysis. A 6-mm-diameter probe was used to penetrate the midpoint between the rind and the core ends of samples to 10 mm at a speed of 2 mm/s. Maximum force (kilograms) and the area under the curves were recorded using the Texture Expert software version 1.22 (Texture Technologies).

**Color analysis.** Color was measured with a Hunter Miniscan XE colorimeter (Hunter Associates Laboratories, Reston, VA) using a 1.9-cm measuring aperture. The colorimeter was calibrated with the standard white and black tiles. D65-10° was used as the illuminant-viewing geometry. The surface color of four cubes from each replicate of each treatment was measured;  $L^*$ ,  $a^*$ , and  $b^*$  were recorded at two opposite sides of each cube. Measurements were made at the midpoint between the rind and core ends. Hue ( $h$ ) and

chroma ( $C^*$ ) values were calculated with the following equations:  $h = \tan^{-1}(b^*/a^*)$  and  $C^* = (a^{*2} + b^{*2})^{1/2}$ .

**Titrateable acidity, pH, and soluble solids content.** Juice extracted from cantaloupe cubes using a Champion MAR-48C juicer (Plastaket Mfg. Co., Lodi, CA) was frozen in a  $-80^\circ\text{C}$  freezer, shipped on dry ice to the USDA Agricultural Research Service Tree Fruit Research Laboratory, and thawed before analysis. The pH was recorded before titration. Titrateable acidity was measured by titrating a 5-ml aliquot of juice to pH 8.1 with 0.1 N KOH with an autotitrator (Radiometer Analytical, Lyon, France) and was expressed as milligrams of malic acid per 100 ml of juice. Soluble solids content was measured using a hand-held refractometer (Atago, Tokyo, Japan).

**Analysis of ascorbic acid.** Samples (10 g) were homogenized with 20 ml of 5% (62.5 mM) metaphosphoric acid with a homogenizer (Virtishear, Virtis, Gardiner, NY) at a speed setting of 70 for 1 min. The homogenate was filtered through four layers of cheesecloth, and the filtrate was centrifuged at  $12,000 \times g$  for 10 min at  $5^\circ\text{C}$ . The supernatant was filtered through a 0.45- $\mu\text{m}$ -pore-size Acrodisc LC 13 PVDF syringe filter (Gelman Sciences, Ann Arbor, MI) and then analyzed with a Hewlett Packard Ti-series 1050 high-performance liquid chromatography system (Agilent Technologies, Palo Alto, CA). Separation of compounds was achieved with an Aminex HPLC-87H organic acids column (300 by 7.8 mm) fitted with a Microguard cation  $\text{H}^+$  (Bio-Rad Laboratories, Hercules, CA) eluted with a mobile phase of 5 mM sulfuric acid at a flow rate of 0.5 ml/min. Ascorbic acid was monitored at 245 nm and calculated from an ascorbic acid standard curve.

**Drip loss.** The overall weight of samples and the amount of juice accumulated in the clamshell containers of fresh-cut cantaloupes were determined at 0, 1, 7, 11, and 14 days of storage. Drip loss was expressed as the percentage of the juice weight divided by the initial weight of sample in the containers.

**Sensory evaluation.** Sensory evaluation (visual quality and aroma) was conducted using a nine-point subjective hedonic scale (2, 3). For visual quality, 9 = excellent quality, essentially free from defects, fresh appearing; 7 = good quality, minor defects, minor visible loss of orange hue; 5 = fair quality, pale orange hue, slight to moderate objectionable defects (such as soggy edges), lower limit of sales appeal; 3 = poor quality, excessive defects, obvious pale to whitish discoloration, slimy surface on some cubes; 1 = extremely poor quality, not usable, visible mold, slimy. For aroma, 9 = strong, characteristic cantaloupe odor; 7 = pleasant, mild cantaloupe odor, slightly "flat"; 5 = bland, faint cantaloupe odor, detectable off-odor; 3 = mild sour or other off-odors; 1 = distinct strong off-odor, fermented like. Three judges independently performed subjective assessments on each sampling day for all samples. Aroma was assessed only in the second trial. In addition, 10 nontrained panelists evaluated the samples in the second trial in which freshly prepared cut cantaloupes also were included as another control. Each piece of cantaloupe was enclosed in a 2-oz (60-ml) polystyrene container for 30 min at ambient temperature before being presented to panelists. Each sample was labeled with random digital numbers.

**Experimental design and statistical analysis.** The experiments were conducted twice as a randomized complete block with three or four replicates for each trial. The data were analyzed by combining the two trials. Randomized complete block analysis of



TABLE 1. *Effect of sanitizers on aerobic plate counts (APCs) and yeast and mold populations on the rinds of whole cantaloupes*<sup>a</sup>

Treatment	APC (log CFU/cm <sup>2</sup> )	Yeasts and molds (log CFU/cm <sup>2</sup> )
Control	4.8 ± 0.8 A	3.9 ± 0.4 A
Chlorine	4.0 ± 1.3 AB	2.3 ± 0.6 D
Acidified sodium chlorite	3.3 ± 0.6 B	2.3 ± 0.5 D
Acidified calcium sulfate	4.0 ± 0.4 AB	3.3 ± 0.5 B
Peroxyacetic acid	4.1 ± 1.1 AB	3.0 ± 0.6 BC
Acidified calcium sulfate + peroxyacetic acid	3.5 ± 0.8 B	2.5 ± 0.4 CD

<sup>a</sup> Values are means ± SD (*n* = 4). Means with the same letter are not significantly different (*P* > 0.05).

variance was used to separate the variance between trials from the experimental variation. Orthogonal polynomial contrasts were constructed to test for linear and quadratic storage trends. Multiple comparisons between treatments were made using the Bonferroni least significant difference method to obtain an experiment error rate of *P* = 0.05 to test for sanitizer storage effect. All statistical analyses and calculations of means and standard deviations (SD) were performed using SAS version 8e (SAS Institute, Inc., Cary, NC). Only significant (*P* < 0.05) results are discussed unless otherwise stated.

RESULTS

**Rind microbial populations.** The effect of different wash treatments on the APCs and yeast and mold populations on the rind of the whole cantaloupe is shown in Table 1. Compared with the water wash (control), chlorine, ACS, and PAA did not result in any significant reduction in APCs, whereas ASC and the combination of ACS and PAA resulted in a significant 1.3- to 1.5-log reduction. However, the yeast and mold counts were significantly reduced by all sanitizer treatments as compared with the water wash. The reductions ranged from 0.6 log CFU/cm<sup>2</sup> for ACS to 1.6 log CFU/cm<sup>2</sup> for the chlorine and ASC treatments.

**Microbial populations on fresh-cut cantaloupes.** The effects of different washing treatments on the APCs and the yeast and mold populations on the surface of fresh-cut cantaloupes prepared from treated whole fruit are shown in Tables 2 and 3, respectively. ACS, ASC, and the combi-

nation of ACS and PAA significantly reduced APCs by up to 1.2 log CFU/g on the fresh-cut cantaloupes at day 1, and lower APCs were maintained throughout the 14-day storage period. Neither PAA nor chlorine had any significant effect on APCs throughout the storage period. During the 14-day storage period, APCs of all cut cantaloupe increased by at least 4 log CFU/g, with the greatest increases occurring in control and PAA-treated samples. None of the treatments consistently reduced yeast and mold populations on the surface of fresh-cut cantaloupes (Table 3). Compared with the control, ASC significantly reduced yeast and mold populations on only days 7 and 11.

**Reduction of *Salmonella* Poona on rind.** The population of inoculated *Salmonella* Poona on the rind of unwashed whole cantaloupe was 3.5 log CFU/cm<sup>2</sup> (data not shown). Water wash (control) did not lower populations of *Salmonella* on cantaloupe rinds (Table 4). Even though all sanitizers reduced populations of *Salmonella* on the rind, only ASC and chlorine had a significant effect (*P* < 0.05). When injured *Salmonella* cells are included, the populations of *Salmonella* on the rind of cantaloupe were significantly reduced by ASC, chlorine, and the combination of ACS and PAA. ASC was the most effective, reducing the population by 1.7 log CFU/g (Table 4). Control cantaloupes carried similar numbers of injured *Salmonella* cells; therefore, the injury may not have been due to sanitizers.

***Salmonella* populations on fresh-cut cantaloupes.** The population of *Salmonella* Poona on the cut fruit prepared from the water-treated (control) whole cantaloupes was 1.0 ± 0.1 log CFU/g. *Salmonella* on cut fruit did not increase during storage of up to 14 days at 4°C, with populations of 0.6 ± 0.3, 0.5 ± 0.8, and 0.8 ± 0.9 log CFU/g on days 7, 11, and 14, respectively. Compared with the control, all sanitizer treatments reduced the population of *Salmonella* on the cut fruit to nondetectable levels (detection limit of 0.4 log CFU/g) (data not shown). All cut fruit samples prepared from the control whole cantaloupes were positive for *Salmonella* by direct plating; therefore, enrichments cultures were not prepared for control samples.

*Salmonella* was not consistently detected by direct enumeration from fresh cut samples prepared from whole cantaloupes after sanitizer treatments. Enrichment cultures

TABLE 2. *Effect of chemical sanitization of whole cantaloupes on aerobic plate counts (APCs) of fresh-cut cantaloupes stored at 4°C*<sup>a</sup>

Treatment	APC (log CFU/g) during storage				LSD <sup>b</sup>
	Day 1	Day 7	Day 11	Day 14	
Control	3.0 ± 0.6 A	4.5 ± 1.0 A	6.8 ± 1.3 A	8.1 ± 0.8 A	1.0
Chlorine	2.6 ± 0.7 AB	4.0 ± 1.1 AB	6.0 ± 1.3 AB	7.1 ± 1.3 AB	1.2
Acidified sodium chlorite	1.9 ± 0.7 BC	2.3 ± 1.2 C	4.5 ± 1.4 C	6.0 ± 1.6 B	1.3
Acidified calcium sulfate	1.8 ± 0.7 C	2.7 ± 1.1 C	4.5 ± 1.6 C	6.0 ± 1.3 B	1.3
Peroxyacetic acid	2.4 ± 0.9 ABC	4.4 ± 1.1 A	6.5 ± 1.5 A	8.0 ± 1.0 A	1.2
Acidified calcium sulfate + peroxyacetic acid	1.9 ± 0.6 BC	3.0 ± 0.6 BC	4.9 ± 0.8 BC	6.1 ± 1.1 B	0.8

<sup>a</sup> Values are means ± SD (*n* = 6). Within the same column, means with the same letter are not significantly different (*P* > 0.05).  
<sup>b</sup> Least significant difference at *P* < 0.05 for the storage effect.

TABLE 3. Effect of chemical sanitization of whole cantaloupes on yeast and mold populations of fresh-cut cantaloupes stored at 4°C<sup>a</sup>

Treatment	Yeasts and molds (log CFU/g) during storage				LSD <sup>b</sup>
	Day 1	Day 7	Day 11	Day 14	
Control	2.5 ± 0.5 A	2.9 ± 0.2 AB	4.0 ± 0.9 A	4.0 ± 1.0 A	1.0
Chlorine	2.0 ± 0.8 AB	2.6 ± 0.2 ABC	2.9 ± 0.4 AB	3.3 ± 1.0 A	1.0
Acidified sodium chlorite	2.0 ± 0.8 AB	2.1 ± 0.4 C	2.6 ± 0.7 B	2.9 ± 0.6 A	1.0
Acidified calcium sulfate	1.8 ± 0.9 AB	2.7 ± 0.6 ABC	3.4 ± 0.2 AB	3.3 ± 0.6 A	1.0
Peroxyacetic acid	1.5 ± 0.6 B	3.1 ± 0.6 A	3.1 ± 1.5 AB	3.6 ± 1.6 A	1.5
Acidified calcium sulfate + peroxyacetic acid	1.8 ± 0.8 AB	2.3 ± 0.7 BC	2.4 ± 0.5 B	2.7 ± 0.5 A	1.0

<sup>a</sup> Values are means ± SD (n = 6). Within the same column, means with the same letter are not significantly different (P > 0.05).  
<sup>b</sup> Least significant difference at P < 0.05 for the storage effect.

were prepared for cut fruit samples that were negative for *Salmonella* by direct plating. After enrichment of the fresh-cut samples, the fewest *Salmonella*-positive samples were found consistently among the ASC-treated samples during the 14-day storage period, whereas the ACS- and PAA-treated samples were generally positive for *Salmonella* (Table 5). Therefore, if whole cantaloupe were contaminated with *Salmonella* at 3 to 4 log CFU/cm<sup>2</sup>, none of the treatments would consistently reduce *Salmonella* to below 0.4 log CFU/g on fresh-cut product.

**Soluble solids content, pH, and titratable acidity.** No significant change was observed in soluble solids content of fresh-cut cantaloupes during storage. Soluble solids content was generally in the range of 8 to 9% during the 14 days of storage. The only treatment that significantly impacted soluble solids content was chlorine, which reduced soluble solids content (8.2 versus 8.8%) on day 11 of the second trial (data not shown).

None of the treatments had a consistent effect on pH of cut cantaloupes during storage with the exception of day 1, when the combination of ACS and PAA resulted in a

decreased pH (6.1 versus 6.3), suggesting possible acidification of fresh-cut samples (data not shown).

Increases in titratable acidity of cut cantaloupes during storage were observed for control, ACS-treated, and PAA-treated samples (data not shown). An increase in titratable acidity in PAA-treated samples was observed later in the storage period (days 11 and 14) and was correlated with deterioration in the sensory quality of the fruit (appearance and aroma). None of the treatments had a consistent effect on titratable acidity, even though significant differences were observed among the treatments for most sampling dates. Titratable acidity of samples treated with the combination of ACS and PAA was higher than that of the control on day 1, corresponding to the decrease in pH.

**Color, firmness, drip loss, and ascorbic acid.** The color parameters (L\*, a\*, and b\*) of the samples did not significantly change during the entire storage period (data not shown), and none of the treatments had a consistent effect on firmness (data not shown). After 14 days of storage, samples treated with ACS or PAA were significantly firmer than the controls (4.4 and 4.0 versus 3.4 area/1,000).

Compared with the control, drip loss was not significantly affected by any of the treatments; however, during storage, drip loss increased in most of the samples (data not shown). Even so, the drip loss was below 3% after 14 days of storage.

Ascorbic acid was not significantly affected by any of the treatments (data not shown). However, samples treated with ASC always had the lowest ascorbic acid content throughout the storage period. On average, ascorbic acid content of ASC samples was 6.7% lower than that of the control. No significant change in ascorbic acid was observed during storage in any of the trials.

**Sensory.** None of the treatments consistently impacted the appearance of the cut cantaloupes (Table 6). The appearance scores for samples treated with ASC and the combination of ACS and PAA were higher than that for the controls at day 14. PAA treatment resulted in lower appearance scores than those for the controls on days 11 and 14. All appearance scores were above 5 (acceptable) even after 14 days of storage.

TABLE 4. Effect of sanitizers on *Salmonella* Poona on the rinds of whole cantaloupes<sup>a</sup>

Treatment	<i>Salmonella</i> (log CFU/cm <sup>2</sup> ) <sup>b</sup>	
	XLT-4	TSA with XLT-4 overlay
Control	3.5 ± 1.0 A	4.3 ± 1.0 A
Chlorine	2.6 ± 0.5 BC	3.4 ± 0.4 B
Acidified sodium chlorite	2.0 ± 0.8 C	2.6 ± 0.8 C
Acidified calcium sulfate	2.8 ± 0.8 ABC	3.6 ± 0.5 AB
Peroxyacetic acid	3.0 ± 0.7 AB	3.8 ± 0.6 AB
Acidified calcium sulfate + peroxyacetic acid	2.7 ± 0.5 ABC	3.4 ± 0.5 B

<sup>a</sup> *Salmonella* Poona cells were directly enumerated on XLT-4. Injured *Salmonella* Poona cells were enumerated using TSA plus XLT-4 overlay.  
<sup>b</sup> Populations were determined 24 h after sanitization treatments and are expressed as means ± SD (n = 4), with a detection limit of 0.4 log CFU/cm<sup>2</sup>. Means with the same letter are not significantly different (P > 0.05).

TABLE 5. Effect of chemical sanitization of whole cantaloupes on the presence of *Salmonella* Poona on fresh-cut cantaloupes stored at 4 °C<sup>a</sup>

Treatment	No. of <i>Salmonella</i> -positive samples during storage <sup>b</sup>			
	Day 1	Day 7	Day 11	Day 14
Control	6	6	6	6
Chlorine	6	6	3	4
Acidified sodium chlorite	3	3	3	2
Acidified calcium sulfate	6	6	6	6
Peroxyacetic acid	5	6	6	4
Acidified calcium sulfate + peroxyacetic acid	6	6	6	5

<sup>a</sup> Samples that were negative for *Salmonella* Poona by direct enumeration were tested for the presence of *Salmonella* by selective enrichment in selenite cystine broth and isolation on XLT-4.

<sup>b</sup> Six samples were tested at each time for each treatment.

The aroma scores of cut fruit prepared from chlorine-treated cantaloupes were lower than those for the control on days 1 and 7. PAA treatment resulted in significantly lower aroma scores than those of the control on most of the sampling days (1, 11, and 14; Table 7), and the aroma scores were below acceptable values (<5) on days 11 and 14. However, the combination of PAA with ACS offset the negative effect of PAA; the aroma scores of the samples treated with the combination treatment were among the highest on days 11 and 14. After 14 days of storage, samples treated with ACS and the combination of ACS and PAA had significantly higher aroma scores than did the controls and were the only samples that had aroma scores higher than 6.

The untrained panelists could not detect any difference in appearance and aroma between the treated samples and the controls (water wash) during the entire storage period (data not shown). However, compared with freshly prepared cut samples, samples treated with chlorine or PAA had lower appearance and aroma scores than did the controls on day 14. The panelists could not distinguish samples treated with water (controls), ACS, ASC, or the combination of

ACS and PAA from the freshly prepared samples in terms of appearance and aroma.

DISCUSSION

Organic acids in sanitizing solutions can inactivate or inhibit the growth of pathogens (5, 14). The inhibition of bacteria by acids results from both a decrease in the intracellular pH and the specific effects of particular undissociated acids on metabolic or other physiological activities such as oxygen consumption and ATP production and alteration of cell membrane permeability (10, 13).

ACS and ASC consistently reduced APCs on cut cantaloupes during storage, which resulted in a 2-log reduction of the APC later in the storage period (days 7 to 14), compared with the other treatments (Table 2). Chlorine and PAA did not significantly reduce APCs on any of the sampling days. ACS did not significantly reduce APCs on rinds of whole cantaloupes (Table 1) but did consistently result in less contamination of the fresh-cut samples, suggesting that ACS may have injured the natural flora and impaired its survival on the flesh of the cantaloupe. ACS and ASC applied to whole fruit reduced populations of bacteria on fresh-cut samples but had no effect on yeasts and molds (Tables 2 and 3), which generally are less sensitive to free sulfurous acid than are bacteria (10).

Yuk et al. (26) applied chlorine, ASC, and PAA to the smooth surface, stem scar, and puncture wounds of tomatoes that had been inoculated with *Salmonella* and found that the sanitizers were more effective for reducing *Salmonella* populations on smooth surfaces than on the stem scar or puncture wounds. The combination of the sanitizers was more effective than the individual sanitizers alone for reducing *Salmonella* in the stem scar and puncture wound areas. PAA applied on whole mango fruit followed by PAA or ASC applied to cut fruit effectively reduced microbial growth and kept microbial counts low on cut fruit surfaces for 21 days (18). In our study, none of the sanitizers achieved more than a 2-log reduction in APCs and yeast and mold populations on the surface of the cantaloupes. The rough surface of whole cantaloupes likely limited the efficacy of the sanitizers in the present study. However, sanitizer residue carried from whole cantaloupes to the cut

TABLE 6. Effect of chemical sanitization of whole cantaloupe on appearance score of fresh-cut cantaloupes stored at 4 °C

Treatment	Appearance score during storage <sup>a</sup>				LSD <sup>b</sup>
	Day 1	Day 7	Day 11	Day 14	
Control	7.6 ± 0.7 A	7.3 ± 0.5 AB	6.8 ± 0.6 BC	6.2 ± 0.5 BC	0.3
Chlorine	7.5 ± 0.4 AB	7.3 ± 0.4 AB	7.1 ± 0.6 A	6.4 ± 0.5 AB	0.2
Acidified sodium chlorite	7.6 ± 0.4 A	7.4 ± 0.5 A	7.0 ± 0.4 AB	6.5 ± 0.5 A	0.2
Acidified calcium sulfate	7.3 ± 0.7 B	7.3 ± 0.5 AB	6.7 ± 0.5 DC	6.4 ± 0.7 AB	0.3
Peroxyacetic acid	7.5 ± 0.6 AB	7.1 ± 0.6 B	6.6 ± 0.4 D	6.1 ± 0.7 C	0.2
Acidified calcium sulfate + peroxyacetic acid	7.7 ± 0.5 A	7.2 ± 0.5 B	7.0 ± 0.4 AB	6.5 ± 0.5 A	0.2

<sup>a</sup> Values are means ± SD (scale of 9 to 1) (n = 8). Within the same column, means with the same letter are not significantly different (P > 0.05).

<sup>b</sup> Least significant difference at P < 0.05 for the storage effect.

TABLE 7. Effect of chemical sanitization of whole cantaloupe on aroma of fresh-cut cantaloupes stored at 4 °C

Treatment	Aroma score during storage <sup>a</sup>				LSD <sup>b</sup>
	Day 1	Day 7	Day 11	Day 14	
Control	8.0 ± 0.6 A	7.4 ± 0.9 A	6.3 ± 1.0 CD	5.2 ± 1.6 C	0.7
Chlorine	7.4 ± 0.4 BC	6.8 ± 0.4 C	6.5 ± 0.7 BC	5.7 ± 1.1 BC	0.5
Acidified sodium chlorite	7.7 ± 0.4 ABC	6.9 ± 0.5 BC	6.0 ± 0.3 D	5.6 ± 0.9 BC	0.4
Acidified calcium sulfate	7.8 ± 0.6 AB	6.4 ± 0.6 D	6.9 ± 0.5 AB	6.2 ± 1.1 AB	0.5
Peroxyacetic acid	7.4 ± 0.6 C	7.2 ± 0.4 AB	3.1 ± 0.9 E	4.3 ± 1.1 D	0.5
Acidified calcium sulfate + peroxyacetic acid	7.6 ± 0.7 BC	7.1 ± 0.6 ABC	7.1 ± 0.5 A	6.5 ± 0.5 A	0.4

<sup>a</sup> Values are means ± SD (scale of 9 to 1) (n = 8). Within the same column, means with the same letter are not significantly different (P > 0.05).  
<sup>b</sup> Least significant difference at P < 0.05 for the storage effect.

fruit may have provided some protection against growth of microorganisms. The quantification of the sanitizer carried from whole fruit to cut cantaloupes would be important. Because most sanitizers used in the present study had a pH below 3.0, we attempted to analyze sanitizer carryover by measuring pH changes of cut cantaloupes. However, there was no significant change in pH. Further study is needed to accurately quantify the amount of sanitizer on the fresh-cut cantaloupes.

In previous studies, ASC was more effective than many other sanitizers for inactivating pathogens and microflora on fresh produce (12, 21). Our results confirmed these results on whole cantaloupes and further demonstrated that sanitization of whole cantaloupes with ASC resulted in fewer *Salmonella*-positive samples and a lower total microbial population on fresh-cut cantaloupes.

Many studies have been conducted to investigate the efficacy of sanitizers for inactivating *Salmonella* on whole melons and fresh-cut fruits. However, this study is the first to follow the *Salmonella* population from the surface of whole cantaloupe to fresh-cut fruit and during simulated commercial storage. The surviving *Salmonella* did not grow on fresh-cut cantaloupe during storage at 4 °C; therefore, storage of fresh-cut fruits at refrigeration temperature is a simple and convenient way to prevent the proliferation of *Salmonella*. However, the recommended storage temperature (1 to 4 °C) often is not obtained during display in supermarkets and in household refrigerators.

Whole cantaloupes sanitized with the acidified compounds were not rinsed because the labels for these materials do not require a freshwater rinse if the fruits are to be processed further. ACS is not likely to be applied directly to fresh-cut cantaloupes or leafy vegetables because of its very low pH, which may cause fruit damage (such as browning). Karabrahimoglu et al. (14) found that a pH below 4 causes browning on fresh-cut apples. The tough, thick surface of whole cantaloupes makes it possible to apply ACS without injury to the flesh. This compound could be used for sanitizing other melons and produce that have tough surfaces so that contamination of fresh-cut products will be reduced.

Among the treatments, PAA was the poorest performer, causing deterioration in quality (including lower sensory

scores for aroma and appearance), increased drip loss, lower pH, and higher acidity. No consistent reduction in APCs or yeasts and molds due to PAA was observed. In contrast, ACS consistently reduced APCs without impacting quality. The effectiveness of ACS for reducing APCs was similar to that of ASC, if not better. However, ACS was not as effective as ASC for reducing *Salmonella*. None of the sanitizers consistently reduced yeasts and molds during storage. Only one concentration of ACS was used in the present study. More studies are needed to investigate the optimum concentration of ACS so that the maximum reduction in microorganisms can be realized without compromising product quality.

The sanitizers used in the present study had limited effect on the population of *Salmonella* inoculated onto the cantaloupes. To increase the efficacy of sanitizers, combination of sanitizers with surfactants may be used. Levulinic acid in combination with sodium dodecyl sulfate (a surfactant) was more effective in reducing microbial populations on meats and lettuce than were many other sanitizers (28). Alternatively, the sanitizers may be applied at elevated temperatures; our studies indicated that hot water reduced the population of *Salmonella* on cantaloupes (1, 11).

Only one concentration for each sanitizer was tested in the present study. These concentrations were either the highest permitted by the FDA or were used based on the manufacturers' recommendations. Results could be different if other concentrations were used. For example, a higher concentration of ACS may be able to achieve greater reduction of *Salmonella* on the surface of cantaloupe.

In summary, sanitization of whole cantaloupes with ACS or ASC significantly reduced native bacterial population on fresh-cut cantaloupes. Even though washing whole melons with the sanitizers often reduced populations of *Salmonella* on the fresh-cut melons, none of the treatments resulted in *Salmonella*-free products at any sampling day during storage. Overall, ASC was the best sanitizer for reducing APCs and *Salmonella* populations. Soluble solids content, pH, acidity, color, drip loss, ascorbic acid, and sensory quality were not consistently affected by any of the treatments, although PAA caused significant quality deterioration in one of the trials. The results indicate that



treatment of whole cantaloupes with some sanitizers at the tested concentrations can achieve a significant reduction in *Salmonella*, yeasts and molds, and APCs on whole fruit and consequently *Salmonella* and APCs on cut fruit; however, *Salmonella* could still be detectable in cut fruit samples.

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## REFERENCES

- Annous, B. A., A. Burke, and J. E. Sites. 2004. Surface pasteurization of whole fresh cantaloupes inoculated with *Salmonella* Poona or *Escherichia coli*. *J. Food Prot.* 67:1876–1885.
- Bai, J. H., R. A. Saffner, A. E. Watada, and Y. S. Lee. 2001. Modified atmosphere maintains quality of fresh-cut cantaloupe (*Cucumis melo* L.). *J. Food Sci.* 8:1207–1211.
- Beaulieu, J. C. 2005. Within-season volatile and quality difference in stored fresh-cut cantaloupe cultivars. *J. Agric. Food Chem.* 53:8679–8687.
- Beuchat, L. R., B. B. Adler, and M. M. Lang. 2004. Efficacy of chlorine and a peroxyacetic acid sanitizer in killing *Listeria monocytogenes* on iceberg and romaine lettuce using simulated commercial processing conditions. *J. Food Prot.* 67:1238–1242.
- Beuchat, L. R., and A. J. Scouten. 2004. Viability of acid-adapted *Escherichia coli* O157:H7 in ground beef treated with acidic calcium sulfate. *J. Food Prot.* 67:591–595.
- Caldwell, K. N., B. B. Adler, G. L. Anderson, P. L. Williams, and L. R. Beuchat. 2003. Ingestion of *Salmonella enterica* serotype Poona by a free-living nematode, *Caenorhabditis elegans*, and protection against inactivation by produce sanitizers. *Appl. Environ. Microbiol.* 69:4103–4110.
- Centers for Disease Control. 1991. Epidemiologic notes and reports, multistate outbreak of *Salmonella* Poona infections—United States and Canada, 1991. *Morb. Mortal. Wkly. Rep.* 40:549–552.
- Centers for Disease Control and Prevention. 2002. Multistate outbreaks of *Salmonella* serotype Poona infections associated with eating cantaloupe from Mexico—United States and Canada, 2000–2002. *Morb. Mortal. Wkly. Rep.* 51:1044–1047.
- Centers for Disease Control and Prevention. 2007. *Salmonella* Oranienburg infections associated with fruit salad served in health-care facilities—northeastern United States and Canada, 2006. *Morb. Mortal. Wkly. Rep.* 56:1025–1028.
- Davidson, P. M., V. K. Juneja, and J. K. Brannen. 2001. Antimicrobial agents, p. 563–620. In A. L. Brannen, P. M. Davidson, S. Salminen, and J. H. Thorngate III (ed.), *Food additives*. Marcel Dekker, New York.
- Fan, X., B. A. Annous, K. J. B. Sokorai, A. Burke, and J. P. Mattheis. 2006. Combination of hot-water surface pasteurization of whole fruit and low-dose gamma irradiation of fresh-cut cantaloupe. *J. Food Prot.* 69:912–919.
- Gonzalez, R. J., Y. Luo, S. Ruiz-Cruz, and J. L. McEvoy. 2004. Efficacy of sanitizers to inactivate *Escherichia coli* O157:H7 on fresh-cut carrot shreds under simulated process water conditions. *J. Food Prot.* 67:2375–2380.
- Ita, P. S., and R. W. Hutkins. 1991. Intracellular pH and survival of *Listeria monocytogenes* Scott A in tryptic soy broth containing acetic, lactic, citric, and hydrochloric acids. *J. Food Prot.* 54(1):15–19.
- Karaibrahimoglu, Y., X. Fan, G. M. Sapers, and K. J. B. Sokorai. 2004. Effect of pH on the survival of *Listeria innocua* in calcium ascorbate solutions and on quality of fresh-cut apples. *J. Food Prot.* 67:751–757.
- Li, Y., R. E. Brackett, R. L. Shewfelt, and L. R. Beuchat. 2001. Changes in appearance and natural microflora on iceberg lettuce treated in warm, chlorinated water and then stored at refrigeration temperature. *Food Microbiol.* 18:299–308.
- Luchansky, J. B., J. E. Call, B. Hristova, L. Rumery, L. Yoder, and A. Oser. 2005. Viability of *Listeria monocytogenes* on commercially-prepared hams surface treated with acidic calcium sulfate and lauric arginate and stored at 4°C. *Meat Sci.* 71:92–99.
- Mehyar, G., G. Blank, J. H. Han, A. Hydamaka, and R. A. Holley. 2005. Effectiveness of trisodium phosphate, lactic acid and commercial antimicrobials against pathogenic bacteria on chicken skin. *Food Prot. Trends* 25:351–362.
- Narciso, J., and A. Plotto. 2005. A comparison of sanitation systems for fresh-cut mango. *HortTechnology* 15:837–842.
- Nunez de Gonzalez, M. T., J. T. Keeton, and L. J. Ringer. 2004. Sensory and physicochemical characteristics of frankfurters containing lactate with antimicrobial surface treatments. *J. Food Sci.* 69: S221–S228.
- Richardson, S. D., A. D. Thurston, Jr., T. V. Caughran, T. W. Collette, K. S. Patterson, and B. W. Lykins, Jr. 1998. Chemical by-products of chlorine and alternative disinfectants. *Food Technol.* 52(4):58–61.
- Rodgers, S. L., J. N. Cash, M. Siddiq, and E. T. Ryser. 2004. A comparison of different chemical sanitizers for inactivating *Escherichia coli* O157:H7 and *Listeria monocytogenes* in solution and on apples, lettuce, strawberries, and cantaloupe. *J. Food Prot.* 67:721–731.
- Ukuku, D. O., V. Pilizota, and G. M. Sapers. 2001. Influence of washing treatments on native microflora and *Escherichia coli* population of inoculated cantaloupes. *J. Food Saf.* 21:31–47.
- U.S. Food and Drug Administration. 2001. FDA survey of imported fresh produce: program information manual. Available at: <http://www.cfsan.fda.gov/~dms/prodsur6.html>. Accessed 6 April 2009.
- U.S. Food and Drug Administration. 2003. FDA survey of domestic fresh produce. Available at: <http://www.cfsan.fda.gov/~dms/prodsu10.html>. Accessed 6 April 2009.
- U.S. Food and Drug Administration. 2008. Guide to minimize microbial food safety hazards of fresh-cut fruits and vegetables. Available at: <http://www.cfsan.fda.gov/~dms/prodgui4.html>. Accessed 6 April 2009.
- Yuk, H. G., J. A. Bartz, and K. R. Schneider. 2005. Effectiveness of individual or combined sanitizer treatments for inactivating *Salmonella* spp. on smooth surface, stem scar, and wounds of tomatoes. *J. Food Sci.* 70:M409–M414.
- Zhao, T., M. P. Doyle, M. C. Kemp, R. S. Howell, and P. Zhao. 2004. Influence of freezing and freezing plus calcium sulfate and lactic acid addition on thermal inactivation of *Escherichia coli* O157:H7 in ground beef. *J. Food Prot.* 67:1760–1764.
- Zhao, T., P. Zhao, and M. P. Doyle. 2009. Inactivation of *Salmonella* and *Escherichia coli* O157:H7 on lettuce and poultry skin by combinations of levulinic acid and sodium dodecyl sulfate. *J. Food Prot.* 72:928–936.